SKEM4153
ROBOT TECHNOLOGY FOR AUTOMATION

CHAPTER 2
ROBOT WORK CELL DESIGN AND CONTROL

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2.1 ROBOT WORK CELL LAYOUTS

- Robot Work Cell Design:
  - Physical design of work cells
  - Control system to coordinate components
  - Evaluation of anticipated performance

2.1 ROBOT WORK CELL LAYOUTS

- Robot Centred Work Cell
- In-Line Robot Work Cell
- Mobile Robot Work Cell

ROBOT CENTRED WORK CELL

- Robot is positioned at approximate centre of work cell
- Other components, equipment are arranged around it
- This layout allows for high utilization of robot
- Parts to be presented in known location and orientation (usage of conveyors, part-feeders, pallets)

ROBOT CENTRED WORK CELL

- This arrangement is suitable for installations where a single robot is servicing one or more production machines.

- Typical applications are:
  - Loading and unloading
  - machining
  - die-casting
  - arc welding
  - plastic moulding

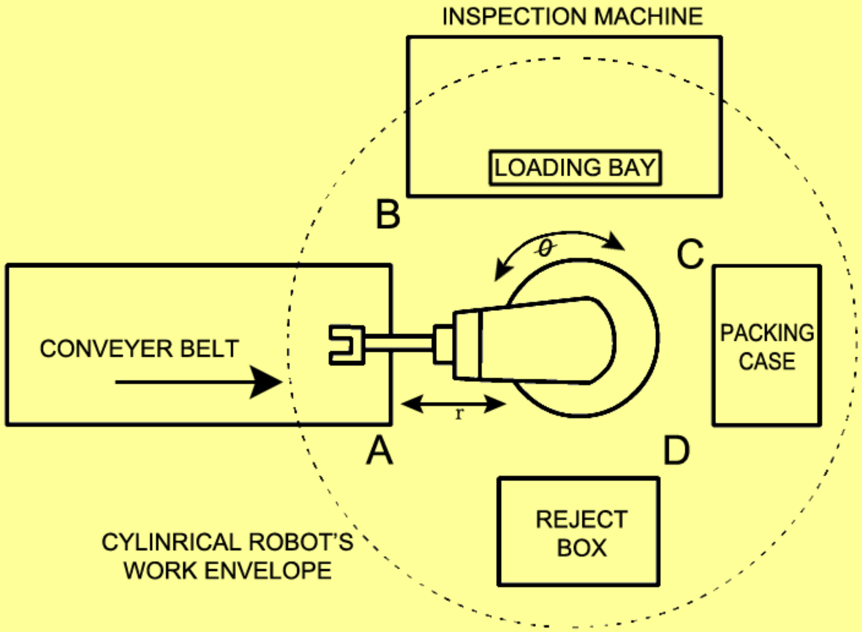


Figure 2.1: Three-machine Robot Centred Cell.

IN-LINE ROBOT WORK CELL

- One or more robots are located along an in-line conveyor or other material transport system.
- Work is organized so that parts are presented to the robots by the transport system. Each robot performs some processing or assembly operation on each part.

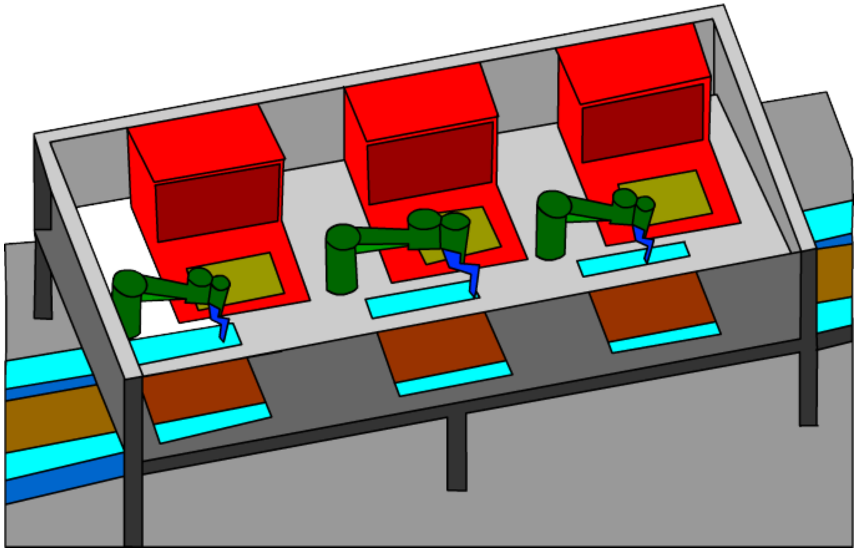


Fig. 2.2 Inline robotic cell layout

IN-LINE ROBOT WORK CELL

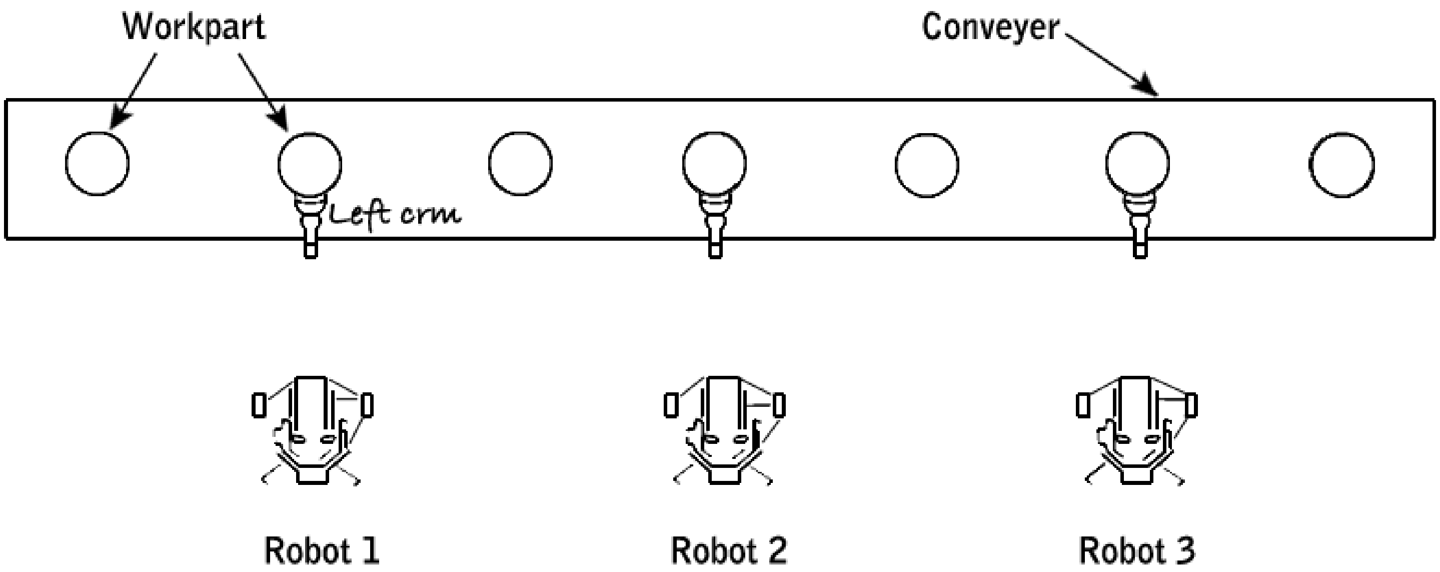


Fig. 2.3 Inline robotic cell layout 1

Typical applications such as in welding lines used to spot-weld car body frames, usually utilizes multiple robots.

IN-LINE ROBOT WORK CELL

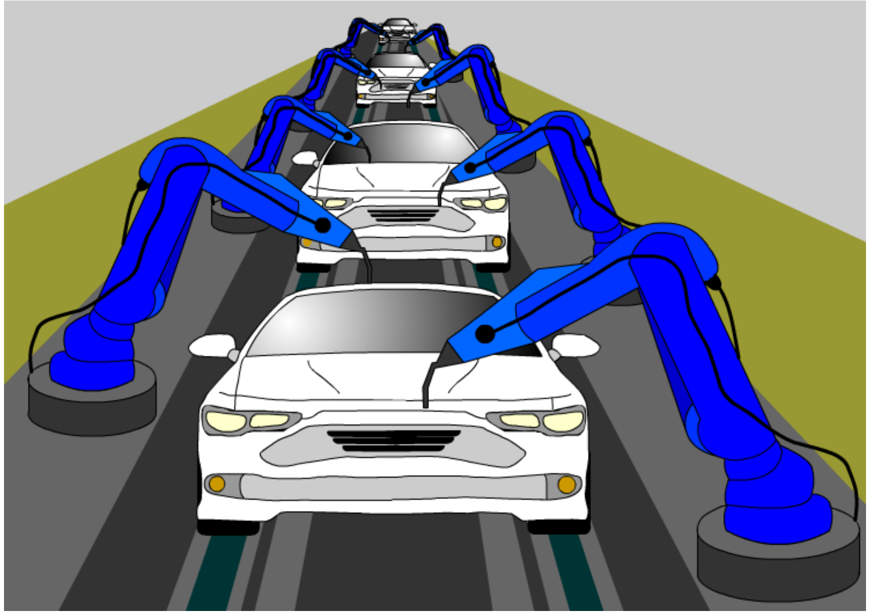


Fig. 2.4 Inline robotic cell layout 2

Typical applications such as in welding lines used to spot-weld car body frames, usually utilizes multiple robots.

IN-LINE ROBOT WORK CELL

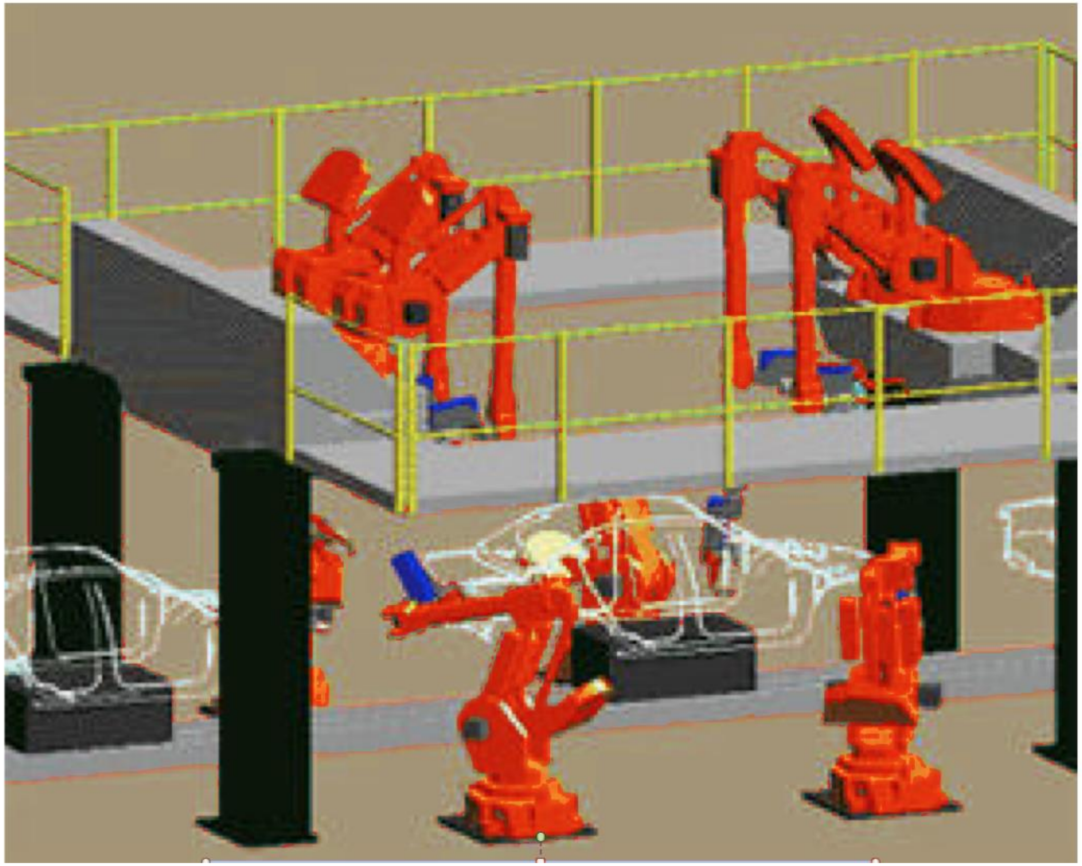


Fig. 2.5 Inline robotic cell layout 3

IN-LINE ROBOT WORK CELL

- There are 3 types of work part transport systems used in in-line robot work cell:
  1. Intermittent Transfer
  2. Continuous Transfer
  3. Non-synchronous Transfer

IN-LINE ROBOT WORK CELL

1. Intermittent Transfer System

- The parts are moved in a start-and-stop motion from one station to another along the line. It is also called synchronous transfer since all parts are moved simultaneously to the next stop.
- The advantage of this system is that the parts are registered in a fixed location and orientation with respect to the robot during the robot's work cycle.

IN-LINE ROBOT WORK CELL

2. Continuous Transfer System
   - Work parts are moved continuously along the line at constant speed. The robot(s) has to perform the tasks as the parts move along.
   - The position and orientation of the parts with respect to any fixed location along the line are continuously changing.
   - This results in a "tracking" problem, that is, the robot must maintain the relative position and orientation of its tool with respect to the work part.
   - This tracking problem can be partly solved by: the moving baseline tracking system by moving the robot parallel to the conveyor at the same speed, or by the stationary baseline tracking system i.e. by computing and adjusting the robot tool to maintain the position and orientation with respect to the moving part.

IN-LINE ROBOT WORK CELL

– The second tracking system involves considerable engineering problems:
  - firstly the robot must have sufficient computational and control capabilities
  - secondly the robot's tracking window must be adequate
  - thirdly the sensor system to identify the different parts coming into the tracking window and also to track the moving part relative to the robot's tool

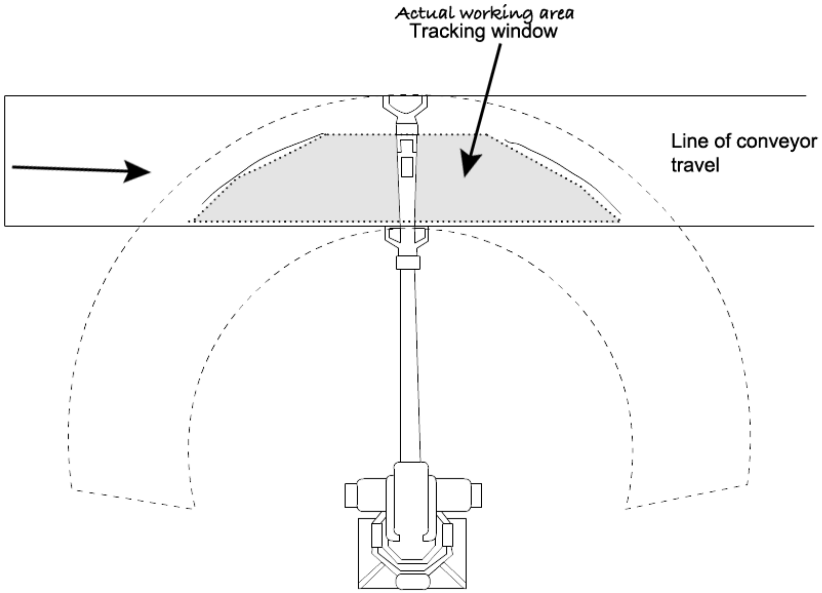


Fig. 2.6 Inline robotic cell layout 4

IN-LINE ROBOT WORK CELL

3. Non-synchronous Transfer System

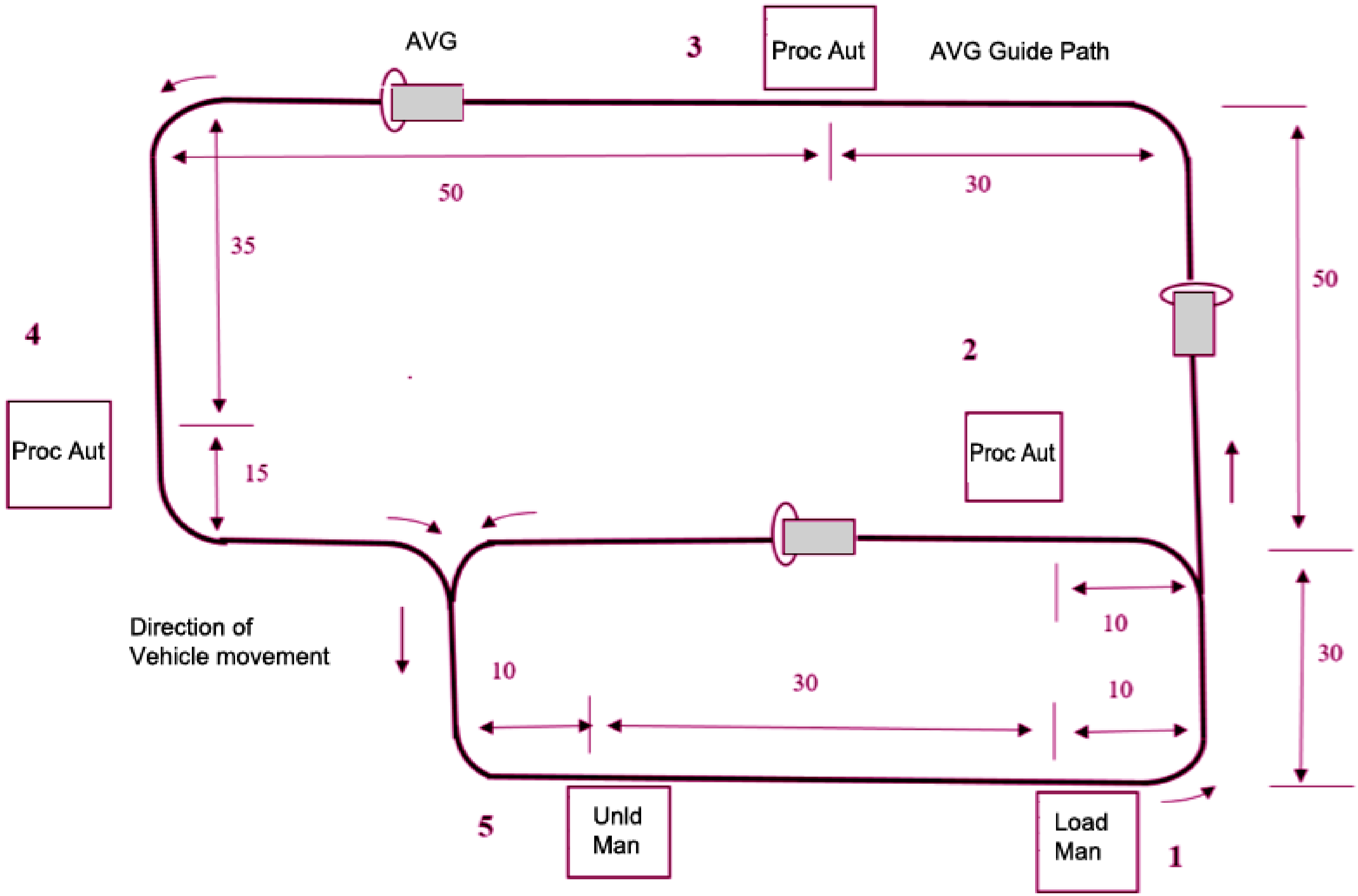
- This is a "power and free system". Each work part moves independently of other parts, in a stop-and-go manner.
- When a work station has finished working on a work part, that part then proceeds to the next work station. Hence, some parts are being processed on the line at the same time that others are being transported or located between stations. Here, the timing varies according to the cycle time requirements of each station.
- The design and operation of this type of transfer system is more complicated than the other two because each part must be provided with its own independently operated moving cart.
- However, the problem of designing and controlling the robot system used in the power-and-free method is less complicated than for the continuous transfer method.

IN-LINE ROBOT WORK CELL

3. Nonsynchronous Transfer System (CONT.)

- For the irregular timing of arrivals, sensors must be provided to indicate to the robot when to begin its work cycle. The more complex problem of part registration with respect to the robot that must be solved in the continuously moving conveyor systems are not encountered on either the intermittent transfer or the non-synchronous transfer.
- Non-synchronous transfer systems offer a greater flexibility than the other two systems.

Example of Non-Synchronous Transport System



MOBILE ROBOT WORK CELL

- In this arrangement, the robot is provided with a means of transport, such as a mobile base, within the work cell to perform various tasks at different locations.

- The transport mechanism can be floor mounted tracks or overhead railing system that allows the robot to be moved along linear paths.

MOBILE ROBOT WORK CELL

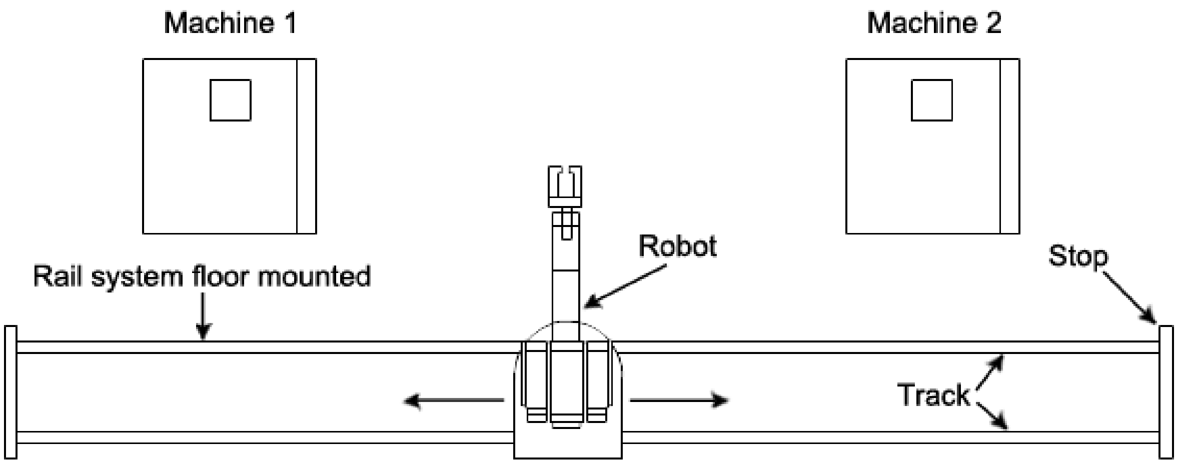


Fig. 2.7 Mobile robot work cell layout 1

- **Mobile robot work cells are suitable for installations where the robot must service more than one station (production machine) that has long processing cycles, and the stations cannot be arranged around the robot in a robot-centred cell arrangement.**

MOBILE ROBOT WORK CELL

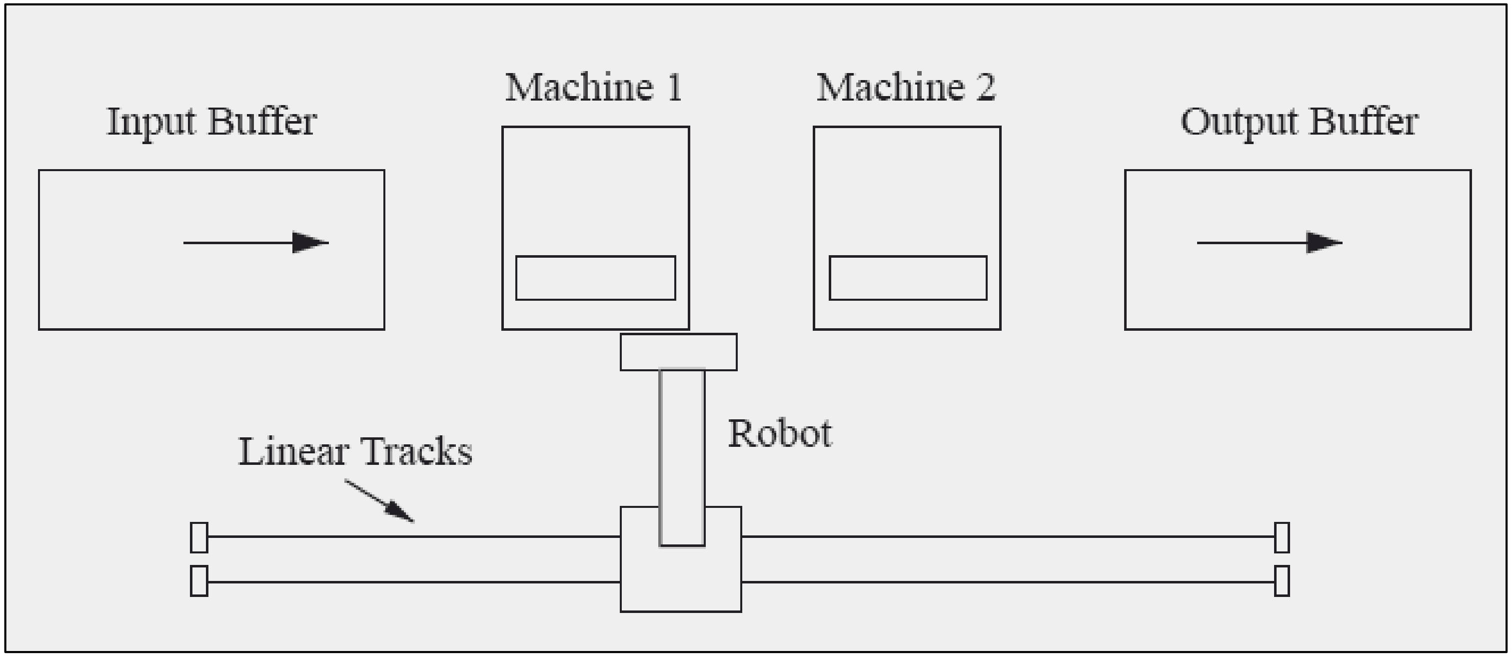


Fig. 2.8 Mobile robot work cell 2

MOBILE ROBOT WORK CELL

- One such reason could be due to the stations being geographically separated by distances greater than the robot's reach. The type of layout allows for time-sharing tasks that will lower the robot idle time.
- One of the problems in designing this work cell is to find the optimum number of stations or machines for the robot to service.

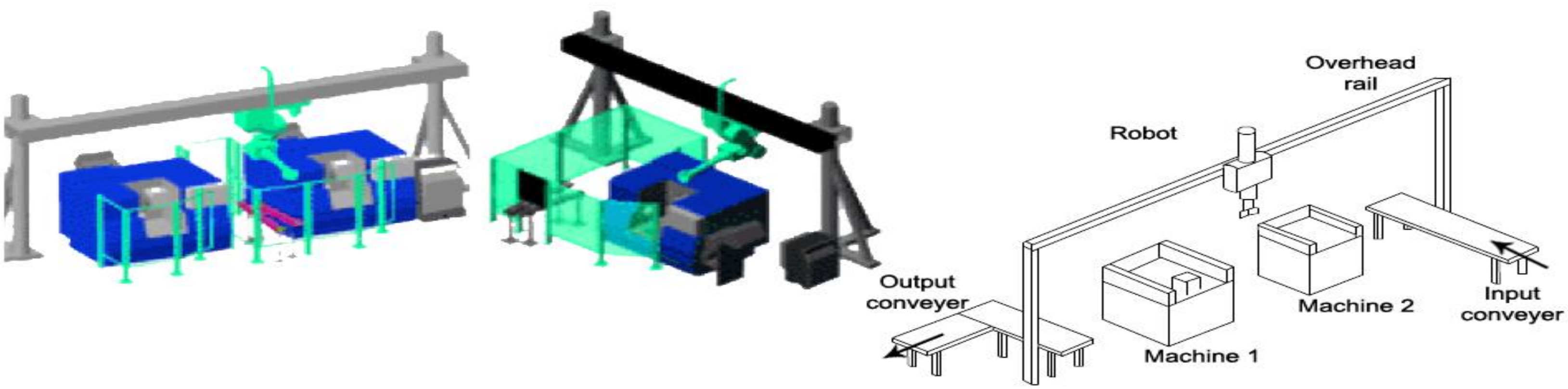


Fig. 2.9 Mobile robot work cell layout 3

2.2 MULTIPLE ROBOTS AND MACHINE INTERFERENCE

Physical Interference of Robots

– Here the work volumes of the robots in the cell are overlapping, posing dangers of collision. Collisions can be prevented by separating the robots so that their work volumes are not overlapping.

– However, there are cases where the robots work on the same component piece or where the robots in turns, work on the component. Here the programmed work cycles of the robots must be coordinated so that they will not be near enough to risk a collision.

2.2 MULTIPLE ROBOTS AND MACHINE INTERFERENCE

Machine Interference

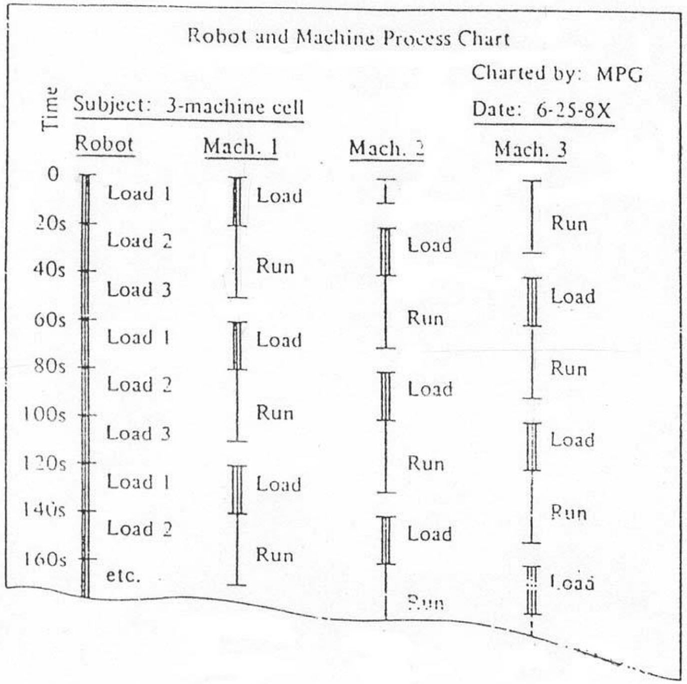
– This occurs when two or more machines are being serviced by one robot. The machine cycles are timed in such a way that idle time is experienced by one or more machines, while one machine is being serviced by the robot. Machine interference can be measured as the total idle time of all the machines in the cell as compared to the operator (or robot) cycle time. The measure is commonly expressed as a percent.

2.2 MULTIPLE ROBOTS AND MACHINE INTERFERENCE

Calculation of Machine Interference

Example 2.1:

- A three-machine cell in which a robot is used to load and unload the machines. Each of the three machines are identical with identical cycles times of 50 s. This cycle time is divided between run time (30 s) and service time (load/unload) by the robot (20 s). The organization of the cycle time is shown in the robot and machine process chart given below.
- It can be seen that each machine has idle time during its cycle of 10 s while the robot is fully occupied throughout its work cycle.



Total idle time of all three machines is 3 x 10 = 30 s

The cycle time of the robot is 3 x 20 = 60 s

Therefore, machine interference is 30 s / 60 s = 50%

2.2 MULTIPLE ROBOTS AND MACHINE INTERFERENCE

Machine Interference

- In the example above, when the robot cycle time is greater than the machine cycle time, there will be resulting machine interference.
- If the machine cycle time is greater than the robot cycle time, there will no machine interference, but the robot will be idle for part of the cycle.
- In cases where the service and run times of the machines are different, the above relationships become complicated by the problem of determining the best sequence of servicing times for the machines into the robot cycle time.

2.3 SOME MODIFICATIONS TO BE MADE

1. Modifications to other equipment in the cell
2. Part position and orientation
3. Part identification problem
4. Protect of robot from its environment
5. Utilities
6. Control of work cell
7. Safety

2.3 SOME MODIFICATIONS TO BE MADE

i. Modifications to other equipment in the work cell

- Modifications need to be done in order to interface robots to equipment in the cell. Special fixtures and control devices must be devised for integrated operation.
- For example, the work holding nests, conveyor stops to position and orientate parts for robots.
- Changes has to be done in machines to allow by robots and use of limit switches and other devices to interface components

2.3 SOME MODIFICATIONS TO BE MADE

ii. Part Position and Orientation

- When parts are being delivered into the work cell, precise pick up locations along conveyors must be established.
- Parts must be in a known position and orientation for the robot to grasp accurately. As the parts are being processed, the orientation must not be lost .
- A way of achieving the above must be designed. For automated feeder systems, the design of the way parts are being presented to the work cell must be provided for.

2.3 SOME MODIFICATIONS TO BE MADE

iii. Part Identification problem

- It there are more than one type of parts, there will be a necessity to identify various parts by automated means, such as optical techniques, magnetic techniques or limit switches that sense different sizes or geometry.
- Electronic tagging may also be used with pallets so that the parts are identified by the information carried by the information card.

iv. Protection of robot from its environment

- In applications such as spray painting, hot metal working conditions, abrasive applications, adhesive sealant applications, the robot has to be protected from possible adverse environment. (e.g. use of sleeves, long grippers).

2.3 SOME MODIFICATIONS TO BE MADE

v. Utilities

- Requirements for electricity, air and hydraulic pressures, gas for furnaces has to be considered and provided for.

vi. Control of the work cell

- The activities of the robot must be coordinated with those of the other equipment in the work cell.

vii. Safety

- Human protection measures such as fences, barriers, safety interrupt system with sensors in and around the work cell must be provided.
- This must be considered even at the early stages of the design of the work cell.

2.4 WORK CELL CONTROL

Basic functions of a work cell

- Sequence Control
- Human (Operator) Interface
- Safety Monitoring

2.4 WORK CELL CONTROL

Sequence Control

This is the basic function of the work cell controller. Sequence control includes:

- regulate the sequence of activities
- control of simultaneous activities
- making decisions to proceed/stop/delay work cycle based on events, such as the use of interlocks to ensure certain elements of the work are completed before other elements are started.

2.4 WORK CELL CONTROL

Example 2.2

In a work cell, the sequence of activities are as follows:

1. Robot picks up raw work part from conveyor at a known pick up location (machine idle)
2. Robot loads part into fixture at machining centre (machine idle)
3. Machining centre begins auto machining cycle (robot idle)
4. Machine completes auto machining. Robot unloads machine and places part on the pallet (machine idle)
5. Robot moves back to pick up point (machine idle)

- Here almost all activities occur sequentially. Therefore, the controller must ensure activities occur in correct sequence and that each step is completed before the next is started.
- Notice that machine idle / robot idle is significant. If we fit a double gripper, productivity can be further improved.

The modified sequence of activities (with double gripper fitted):

1. Robot picks up raw work part using the first gripper from conveyor at a known pick up location. Robot moves its double gripper into ready position in front of machining centre (machine cycle in progress)
2. At completion of machine cycle, robot unloads finished part from the machine fixture with a second gripper and loads raw part into fixture with the first gripper (machine idle)
3. Machining centre begins auto machining cycle. Robot moves finished part to pallet and places it in programmed location on pallet
4. Robot moves back to pick up point (machine cycle in progress)

- In the modified sequence, several activities occur simultaneously – but initiated sequentially.

2.4 WORK CELL CONTROL

Sequence Control

- Therefore controller is to ensure the various control cycles begin at the required times.
- Controller must communicate back and forth with the various equipment (machining centre, conveyors and robot).
- Signals must be sent by the controller, and other signals must be received from the components. These signals are called interlocks.

2.4 WORK CELL CONTROL

Sequence Control

For more sophisticated work cells, there exists other additional functions within the sequence control:

- Logical decision making. To make decision on which action to activate first, giving a certain situation. For example, a work cell processing two or more parts. Depending on which part is being presented, the controller activates different programs of alternative work cycles.
- Computations. In palletizing, each cycle places part in different slots, which requires computation of the new position each time. In path planning, the robot may choose the minimum-time path to go between some given points.
- Irregular elements. These are events that occurs irregularly. For example, tool changes after a certain number of parts have been processed, or exchanging pallets and containers.
- Exceptional events. Coping with exceptional events such as equipment breakdown and recovering from a power failure.

2.4 WORK CELL CONTROL

Human (Operator) Interface

This is to provide a means for operator to interact with robot work cell.

Operator interface is required to:

- Program the robot, modify and update programs
- Let human operator participate in work cycle, such as man and robot each performing a portion of work. Humans involve in tasks that require judgement and sensory capabilities that the robot does not possess.
- Do data entry by human operator such as for part dimensions, part identifications.
- Do emergency stopping of activities.

2.4 WORK CELL CONTROL

Safety Monitoring

- Emergency stopping requires an alert operator to be present to notice the emergency and take action to interrupt the cycle (however, safety emergencies do not always occur at convenient times, when the operator is present).
- Therefore, a more automatic and reliable means of protecting the cell equipment and people who might wander into the work zone, is imperative. This is safety monitoring.
- Safety monitoring (or hazard monitoring) is a work cell control function where sensors are used to monitor status and activities of the cell, to detect the unsafe or potentially unsafe conditions.
- There are various types sensors that can be used for such purpose, for example, limit switches to detect movements has occurred correctly, temperature sensors, pressure sensitive floor mats, light beams combined with photosensitive sensors, and machine vision.

2.4 WORK CELL CONTROL

Safety Monitoring

The safety monitoring is programmed to respond to various hazard conditions in different ways:

- **Complete stoppage of cell activities**
- **Slowing down the robot speed to a safe level when human is present**
- **Warning buzzers to alert maintenance personnel of a safety hazard**
- **Specially programmed subroutines to permit the robot to recover from a particular unsafe event (this is called error detection and recovery)**

2.5 INTERLOCKS

- Interlocks provide means of preventing the work cycle sequence from continuing unless a certain or set of conditions are satisfied.
- This is a very important feature of work cell control, that regulates the sequence of activities being carried out. Interlocks are essential for the coordination and synchronization of activities which could not be accomplished through timing alone.
- Interlocks allow for variations in the times taken for certain elements in the work cycles. In the example case in section 4, interlocks would be used for the following purposes:
  - To ensure that a raw part was at the pick up location, before the robot tries to grasp it
  - To determine when the machining cycle has been completed before robot attempts to load part onto fixture
  - To indicate that the part has been successfully loaded so that the auto machining cycle can start

2.5 INTERLOCKS

- *Input interlocks.* Input interlocks make use of signals sent from the components in the cell to the controller.

  They indicate that certain conditions have been met and that the programmed work sequence can continue. For example a limit switch on work fixture can send a signal to indicate that the part has been properly loaded.

- *Output interlocks*. Makes use of signals sent from the controller to other devices or machines in the work cell.

  In our example an output signal is used to signal the machining centre to commence the auto cycle. The signal is contingent upon certain conditions being met, such as, that work part has been properly loaded and the robot gripper has been moved to a safe distance. These conditions are usually determined by means of input interlocks.

2.5 INTERLOCKS

- In designing the work cell, we must not only consider the regular sequence of events during normal operation, but also the possible irregularities and malfunctions that might happen. In the regular cycle, the various sequential and simultaneous activities must be identified, together with the conditions that must be satisfied.
- For the potential malfunctions, the applications engineer must determine a method of identifying that the malfunction has occurred and what action must be taken to respond to that malfunction.
- Then for both the regular and the irregular events in the cycle, interlocks must be provided to accomplish the required sequence control and hazard monitoring that must occur during the work cycle.
- In some cases, the interlock signals can be generated by the electronic controllers for the machines. For example NC machines would be capable of being interfaced to work cell controller to signal completion of auto machining cycle.
- In other cases, the applications engineer must design the interlocks using sensors to generate the required signals.

2.6 ERROR DETECTION AND RECOVERY (EDR)

- Hardware malfunctions and unexpected events will cause costly delays and loss of production. Usually, in automated processes, human assistance is required to intervene, diagnose and make repairs and then restart the system.
- When a computer is used to detect and correct errors, this is known as “error detection and recovery”.
- The implementation involves the use of sensors and programming.

2.6 ERROR DETECTION AND RECOVERY (EDR)

Error Detection

- Use of appropriate sensors is very crucial in determining when errors have occurred.
- The sensor signals must be interpreted so that errors can be recognized and classified. This needs some form of intelligence in processing the error signals.
- In general, errors in manufacturing can be classified into:
  - **Random errors**: result from stochastic phenomena and characterized by their statistical nature.
    An example of this randomly varying part sizes in a machining operation. If the variation about a mean value is significant, this may give rise to problems in subsequent manufacturing process.
  - **Systematic errors**: not determined by chance, but by some bias that exists in the process.
    For example, incorrect machine setting or fixture setting will likely result in systematic error in the product.
  - **Illegitimate error**: typically resulting from an outright mistake, either by equipment or human error. An example of this error in the robot program.

2.6 ERROR DETECTION AND RECOVERY (EDR)

Example 2.3

For an automated machining cell serviced by a robot, the error categories may include: tooling, work part, process, fixture, machine tool and robot/end-effector. This does not include the safety monitoring system employed in the robot work cell.

Error Source Category	Particular Malfunction or Error
1. Tooling	Tool wear-out, Tool breakage, Vibration (chatter), Tool not present, Wrong tool loaded.
2. Work	Work part not present, Wrong work part, Defective work part or undersized part.
3. Process	Wrong part program, Wrong part, Chip fouling, No coolant when there should be, Vibration (chatter), Excessive force, Cutting temperature is too high.
4. Fixture	Part in fixture (yes or no), Part located properly (yes or no), Clamps actuated, Part dislodged during processing, Part deflection during processing, Part breakage, Chips causing location errors, Hydraulic or pneumatic failure.
5. Machine Tool	Vibration loss of power, Power overload, Thermal deflection, Mechanical failure, Hydraulic or electrical failure.
6. Robot/ end-effector	Improper grasping of work part, No part present at pickup Hydraulic or electrical failure, Loss of positioning accuracy Robot drops part during handling.

2.6 ERROR DETECTION AND RECOVERY (EDR)

Error Recovery

This is concerned with defining and implementing the strategies that can be employed by the robot to correct or compensate for the malfunction that has occurred. Once error classification has been made, specific recovery strategies are developed to deal with each specific type of error.

The recovery strategies can be grouped into some general categories:

- *Adjustments at the end of current cycle*. A relatively low level of urgency. At the end of current cycle, the robot program would branch to a subroutine to make the required corrections, then branch back to the main program.
  Example, the robot dropped a part and the logical action is to go for the next part.
- *Adjustments during current cycle*. Error is sufficiently serious, so corrective action must be taken during the current cycle of operation. However, the process is not stopped. The corrective action is typically accomplished by calling a special subroutine that has been designed to deal with the particular error.
  Example, an oversized part is present, therefore invoke additional program to machine the extra material.

2.6 ERROR DETECTION AND RECOVERY (EDR)

Error Recovery

- ***Stop the process and invoke corrective algorithm***. The error requires the process to be stopped, and a subroutine is called to correct the error. At the end of the correction algorithm, the process can be resumed or restarted.
  Example, tool failure, therefore change tool and replace the damaged part.
- ***Stop the process and call for help***. This is when the malfunction cannot be corrected by the robot or due to an unclassified error to which no corrective algorithm has been designed. Here, human assistance is needed to restore the system.
  Example, hydraulic system break-down, which means automatic recovery is not possible, therefore needs human assistance.

The error detection and recovery system is implemented by means of the sensors used in the work cell together with the robot programming system.

In many requirements, the textual language programming provides distinct advantage in developing the sometimes complex logic needed. For highly sophisticated robot work cells, a major part will require programming.

2.7 WORK CELL CONTROLLER

The work cell controller deals with the coordination of the robot's activities with those of other equipment in the cell

There are a number of candidates for the work cell controller:

- robot controller
- relays
- programmable logic controllers (PLC)
- small stand-alone computers

Which one to use? (Please refer to notes on pp 23-26)

The choice depends on the complexity of the cell, that is

- number of separate control actions
- number of separate pieces of equipment
- number of robots

Can the robot controller alone handle it?

2.8 ROBOT CYCLE TIME ANALYSIS

- The cycle time analysis is important since it is related to production rate and economic viability of robot installation.
- An analysis method known as the RTM (Robot Time and Motion) has been developed at Purdue University. It is used for estimating the time needed to perform a work cycle before setting up a work cell and programming the robot.
- This would enable alternative robot tasks be evaluated. By comparing the performance for a given work cycle, it can also be used as a guide in the selection of the best robot for a particular application.

2.8 ROBOT CYCLE TIME ANALYSIS

The robot work cycle elements can be broadly categorized into:

- *Motion elements*. These are manipulator movements, performed with or without load.
- *Sensing elements*. These are sensory activities performed by robots equipped with sensing capabilities such as vision sensing, force sensing and position sensing.
- *End effector elements*. These elements relate to the action of the gripper or tool attached to the robot wrist.
- *Delay elements*. These are delay times resulting from waiting and processing conditions in the work cycle.

2.8 ROBOT CYCLE TIME ANALYSIS

There are four possible approaches that can be used to determine the element times and analyse a robot cycle with RTM:

- First approach: involves tables of elements, in which time values are determined for different elements listed in Table 2.2.
- Second approach: Develop regression equations for the more complicated elements whose values are functionally related to several factors.
- Third approach: known as "Motion Control", and can be applied to those in the Motion elements. Motion control concerns with kinematics and dynamics analysis of movement. It determines the element time values by considering distances moves and velocities involved. It also considers the acceleration and deceleration at the beginning and end of motion.
- Fourth approach: known as "path geometry". It requires the specification of the motion path to be followed by the robot, as well as the robot joint and arm velocities. It turns out that most robot motions involve simultaneous actuation of several joints, but one of the joints usually predominates because its relative move is the largest.

2.8 ROBOT CYCLE TIME ANALYSIS

Element	Symbol	Definition of element	Element parameters
1	Rn	n-segment reach: Move unloaded manipulator along a path comprised of n segments	Displacement and velocity (or path geometry and velocity)
2	Mn	n-segment move: Move object along path comprised of n segments	Displacement and velocity (or path geometry and velocity)
3	ORn	n-segment orientation: Move manipulator mainly to reorient	Displacement and velocity (or path geometry and velocity)
4	SEi	Stop on position error	Error bound
4.1	SE1	Bring the manipulator to rest immediately without waiting to null out joint errors	
4.2	SE2	Bring the manipulator to rest within a specified position error to tolerance	

2.8 ROBOT CYCLE TIME ANALYSIS

Element	Symbol	Definition of element	Element parameters
5	SFi	Stop on force or moment	Force, torque, and touch
5.1	SF1	Stop the manipulator when the force conditions are met	
5.2	SF2	Stop the manipulator when the torque conditions are met	
5.3	SF3	Stop the manipulator when either the force or torque conditions are met	
5.4	SF4	Stop the manipulator when the touch conditions are met	
6	VI	Vision operation	Time function
7	GRi	Grasp an object	Distance to open/close
7.1	GR1	Simple grasp of object by closing fingers	
7.2	GR2	Grasp object while centering hand over it	
7.3	GR3	Grasp object by closing one finger at a time	
8	RE	Release object by opening fingers	
9	T	Process time delay when robot is part of the process	Time function
10	D	Time delay when robot is waiting for a process completion	Time function

2.8 ROBOT CYCLE TIME ANALYSIS

Element	Symbol	Element time, s	Parameters
1	**R1**	S / V + 0.40 for S>V/2.5	S = distance moved (ft), V = velocity (ft/sec)
		0.40 for S< V/2.5	This is used for short moves
2	**M1**	***For payloads of less than 1.0 lb***	
		S / V + 0.40 for S>V/2.5	S = distance moved (ft), V = velocity (ft/sec)
		0.40 for S<V/2.5	This is used for short moves
		For payloads of between 1 and 5.0 lb	
		S / V + 0.60 for S>V/2.5	S = distance moved (ft), V = velocity (ft/sec)
		0.60 for S< V/2.5	This is used for short moves
		For payloads of between 5 and 15 lb	
		S / V + 0.90 for S>V/2.5	S = distance moved (ft), V = velocity (ft/sec)
		0.90 for S< V/2.5	This is used for short moves
4.1	**SE1**	**0.1V**	V = previous velocity (ft/sec)
7.1	**GR1**	**0.1**	Assumed to be independent of any parameters
8	**RE**	**0.1**	Assumed to be independent of any parameters
9	**T**	***T***	*T* = robot delay time
10	**D**	***D***	*D* = process delay time

2.8 ROBOT CYCLE TIME ANALYSIS

A sketch of the workstation showing distances that the robot must move from one position to the next is shown in Fig. 2.11. The detailed sequence of elements to accomplish the work cycle is presented in Table 2.4.

The conveyor delivers one part every 15 s, so that the work cycle is limited by the conveyor feed rate. The RTM analysis in this problem would be useful for determining whether the time for the robot motion cycle is compatible.

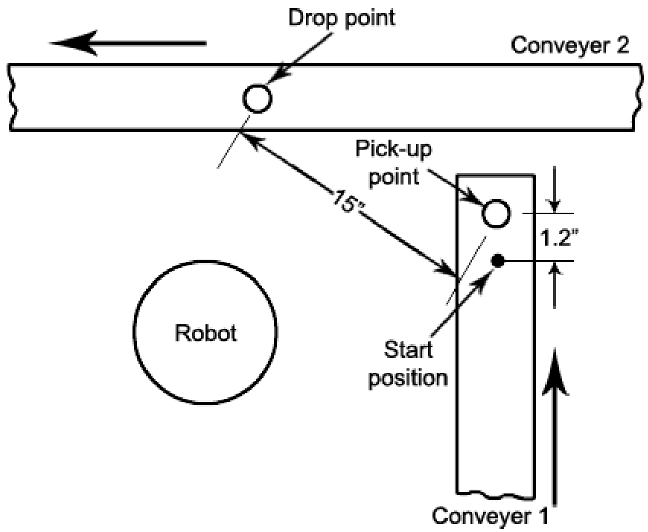


Figure 2.11 Workcell layout for Example 2.4

Example 2.4

This example will illustrate the use of the RTM method. The work cycle consists of a simple task in which the robot must move parts weighing 3 lb from one conveyor to another conveyor. The sequence of the work cycle proceeds as follows:

1. Robot picks up part from first conveyor which has delivered the part to a known pickup position.
2. Robot transfers part to second conveyor and releases part.
3. Robot moves back to ready position at first conveyor.

2.8 ROBOT CYCLE TIME ANALYSIS

Sequence	Element Description
1	Conveyor delivers a part to a fixed position every 15 s. Robot in ready position above conveyor must await part delivery before executing its motion cycle.
2	Robot approaches part with gripper in open position. Speed setting is 0.1 ft/sec.
3	Robot gripper closes on part.
4	Robot lifts part 0.1 ft above conveyor. Speed is 0.1 ft/sec.
5	Robot moves part to a position 0.1 ft above second conveyor. Robot arm speed is 0.5 ft/sec. Distance traveled is 15 in.
6	Robot moves part to conveyor surface. Gripper would have to be oriented so that conveyor motion does not cause immediate tipping of the part when released. Speed is 0.1 ft/sec.
7	Robot gripper opens to release part on conveyor surface.
8	Robot moves empty gripper away from conveyor surface by 0.1 ft. Speed is 0.1 ft/sec.
9	Robot arm returns to ready position 0.1 ft above first conveyor surface.

Distance travelled between conveyor is 15 in. Robot arm speed is 0.5 ft/sec.

2.8 ROBOT CYCLE TIME ANALYSIS

Sequence	Symbol	RTM ft	Distance ft/sec	Velocity, time, s	Delay time, s	Element Description
1	D	–	–	15.0	15.0	Await delivery
2	R1	0.1	0.1	–	1.4	Approach part
3	GR1				0.1	Grasp part
4	M1	0.1	0.1	–	1.6	Lift part
5	M1	1.25	0.5	–	3.1	Move part
6	M1	0.1	0.1	–	1.6	Approach release point
7	RE	–	–	–	0.1	Release part
8	R1	0.1	0.1	–	1.4	Depart release point
9	R1	1.25	0.5	–	2.9	Reposition
	TOTAL				12.2	

TEXT AND REFERENCE BOOKS

Textbook:

1. James A. Rehg: Introduction to Robotics in CIM Systems. Fifth Edition, Prentice-Hall. 2003.

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3. Farid M. L. Amirouche: Computer-Aided Design and Manufacturing. Prentice-Hall.
4. Richard K. Miller, Industrial Robot Handbook. Van Nostrand Reinhold, N.Y. (1987).